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UNUSUALLY SENSITIVE AREAS FOR DRINKING WATER RESOURCES REPORT FOR MARYLAND

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INTRODUCTION

The Research and Special Programs Administration (RSPA) of the Department of Transportation is required to identify areas unusually sensitive to environmental damage in the event of a hazardous liquid pipeline accident, in accordance with pipeline safety laws (49 U.S.C. Section 60109). Accordingly, workshops were held with regulatory agencies, pipeline operators, and the public during which a process was developed to identify "unusually sensitive areas" (USAs) for drinking water resources. This process, which has been adopted by RSPA, consists of first identifying environmentally sensitive drinking water resources and other primary concerns, and then applying the following five filtering criteria to determine which of the drinking water source locations (i.e., surface water intakes, groundwater wells) should be USAs:

Filter Criteria #1

If the public water system is a Transient Noncommunity Water System (TNCWS), the water intakes shall not be designated as USAs.

Filter Criteria #2

For Community Water Systems (CWS) and Nontransient Noncommunity Water Systems (NTNCWS) that obtain their water supply primarily from surface water sources, and do not have an adequate alternative source of water, the water intakes shall be designated as USAs.

Filter Criteria #3

For CWS and NTNCWS that obtain their water supply primarily from groundwater sources, where the source aquifer is identified as a Class I or Class IIa, as defined in Pettyjohn et al. (1991), and do not have an adequate alternative source of water, the wellhead protection areas for such systems shall be designated as USAs.

Filter Criteria #4

For CWS and NTNCWS that obtain their water primarily from groundwater sources, where the source aquifer is identified as a Class IIb, IIc, III, or U, as defined in Pettyjohn et al. (1991), the public water systems that rely on these aquifers shall not be designated as USAs.

Filter Criteria #5

For CWS and NTNCWS that obtain their water supply primarily from groundwater sources, where the source aquifer is identified as a Class I or Class IIa (as defined in Pettyjohn et al., 1991), and the aquifer is designated as a sole source aquifer, an area twice the wellhead protection area shall be designated as a USA.

Filter criteria 2 could not be applied in Maryland because data were not available to determine if surface water sources have an adequate alternative source of water. Therefore, all CWS and NTNCWS that obtain their water from surface water sources are automatically designated as USAs. In Maryland, there are 91 community systems that obtain their water supply primarily from surface water sources, 39 of which utilize above ground springs. Inasmuch as all of the surface water intakes are USAs, the rest of this discussion describes the process that has been developed and implemented to classify groundwater wells that supply the CWS and NTNCWS in the state.

THE PETTYJOHN CLASSIFICATION SCHEME

The aquifer classification scheme developed in a report "Regional Assessment of Aquifer Vulnerability and Sensitivity in the Conterminous United States" for the U.S. Environmental Protection Agency (USEPA/600/2-91/043) by Pettyjohn et al. (1991) is used to determine the parts of an aquifer at risk to contamination from a hazardous liquid pipeline release. The Pettyjohn classification is based on an assessment of the potential contamination of groundwater throughout the United States by the subsurface emplacement of fluids through injection wells. The classification is listed below:

Class I (Surficial or Shallow Permeable Units; Highly Vulnerable to Contamination)
Class Ia: Unconsolidated Aquifers. Consist of surficial, unconsolidated, and permeable alluvial, terrace, outwash, beach, dune and other similar deposits.

Class Ib: Soluble and Fractured Bedrock Aquifers. Consist of limestone, dolomite, and, locally, evaporitic units that contain documented karst features or solution channels, regardless of size. Also includes sedimentary strata and metamorphic and igneous rocks that are significantly faulted, fractured, or jointed.

Class Ic: Semiconsolidated Aquifers. Consist of semiconsolidated systems that contain poorly to moderately indurated sand and gravel that are interbedded with clay and silt.

Class Id: Covered Aquifers. Consists of any Class I aquifer that is overlain by less than 50 feet of low permeability, unconsolidated material, such as glacial till, lacustrian, and loess deposits.

Class II (Consolidated Bedrock Aquifers; Moderately Vulnerable to Contamination)

Class IIa: Higher Yield Bedrock Aquifers. Consist of fairly coarse sandstone or conglomerate that contain lesser amounts of interbedded fine-grained clastics and occasionally carbonate units. In general, well yields must exceed 50 gallons per minute (gpm) to be included in this class.

Class IIb: Lower Yield Bedrock Aquifers. Consist of the same clastic rock types present in the higher yield systems. May also consist of crystalline rocks that are fractured to some degree. Well yields are commonly less than 50 gpm. (Note: We have broadened this definition to include all low-yield, consolidated bedrock aquifers [e.g., crystalline igneous and metamorphic rocks].)

Class IIc: Covered Bedrock Aquifers. Consist of Class IIa and IIb aquifers that are overlain by less than 50 feet of unconsolidated material of low permeability.

Class III (Covered Consolidated or Unconsolidated Aquifers)

This class includes those aquifers that are overlain by more than 50 feet of low permeability material. (Note: We have broadened this definition to include all confined aquifers.)

Class U (Undifferentiated Aquifers)

This classification is used where several lithologic and hydrologic conditions are present within a mappable area. This class is intended to convey a wider range of vulnerability than is usually contained in any other single class.

Subclass v (Variably Covered Aquifers)
The modifier "v" is used to describe areas where an undetermined or highly variable thickness of low permeability sediments overlies the major water-bearing zone. In

practice, we have used this modifier where the geologic description of the aquifer indicates that there is a confining unit above the water-producing zone.

The key to identifying groundwater wells that are USAs is distinguishing wells that obtain water from Class I or Class IIa aquifers (filter criteria 3 and 5), from those that do not (filter criteria 4). Another key is the thickness of overlying, impermeable materials. For example, if Class I and IIa aquifers are overlain by more than 50 feet of impermeable material, such as glacial till or shale, then wells in that area would be Class III and, therefore, not USAs.

IDENTIFYING USAs FOR DRINKING WATER RESOURCES IN MARYLAND

The Pettyjohn Classification of Aquifers in Maryland

The geology of the state of Maryland is complex, inasmuch as it is located within five provinces (Figs. 1 & 2). Most of the eastern half of the state is in the Coastal Plain province, where a number of sedimentary aquifers, mostly sand and sandstones, dip uniformly oceanward. The majority of the wells that derive water from these aquifers are either Class Ia in the aquifer outcrop belt, or Class III where the wells are located outside of the outcrop belt, as shown in Figure 3, because of the presence of confining units under each aquifer. In Figure 3, the circles for the wells are filled with the same color as the aquifer from which they obtain water. Smaller red and black dots are used to denote the Pettyjohn aquifer classification. For the wells which obtain water from the Potomac Group (dark purple), those located in the outcrop belt of the Potomac Group along the edge of the Coastal Plain are Class Ia. All of the other wells outside the outcrop are Class III, because the aquifer dips below other strata which act as confining units. In contrast, there is no confining unit over the Quaternary (or surficial) aquifer, so all of these wells are Class Ia.

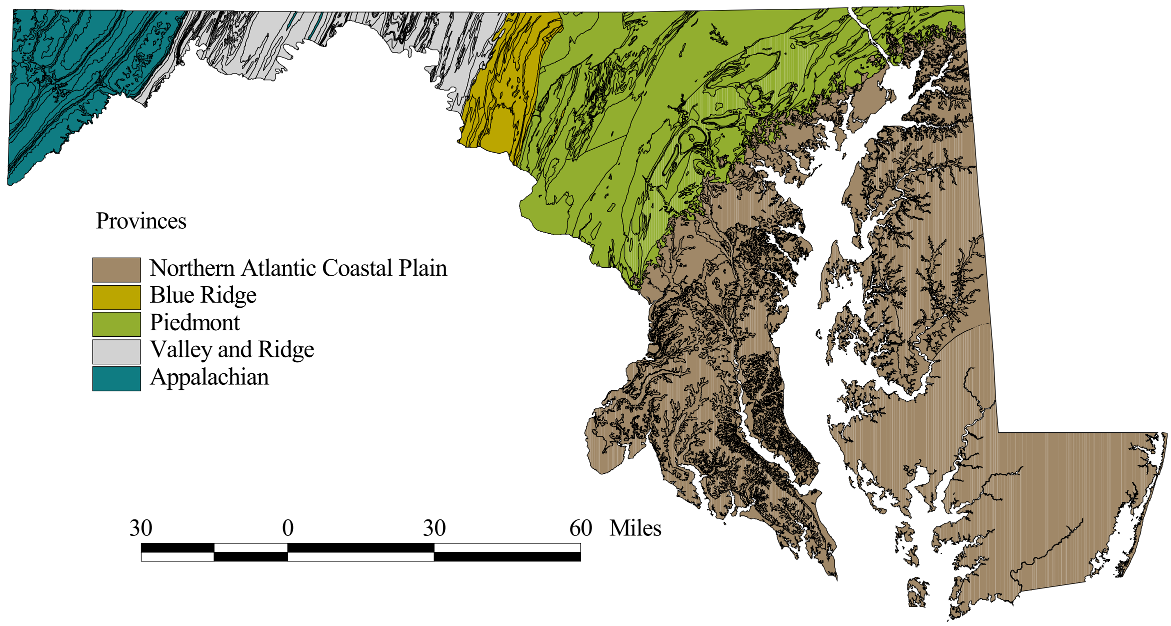

FIGURE 1. The five geological provinces located in Maryland.

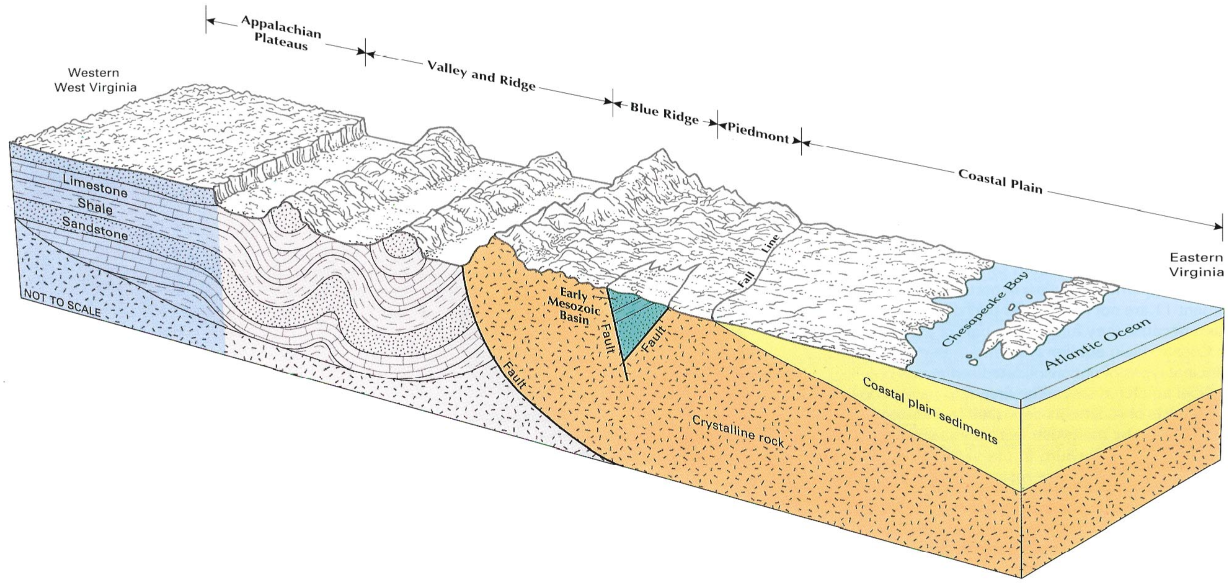

FIGURE 2. Cross sectional view of the five provinces that are in Maryland (USGS 1997).

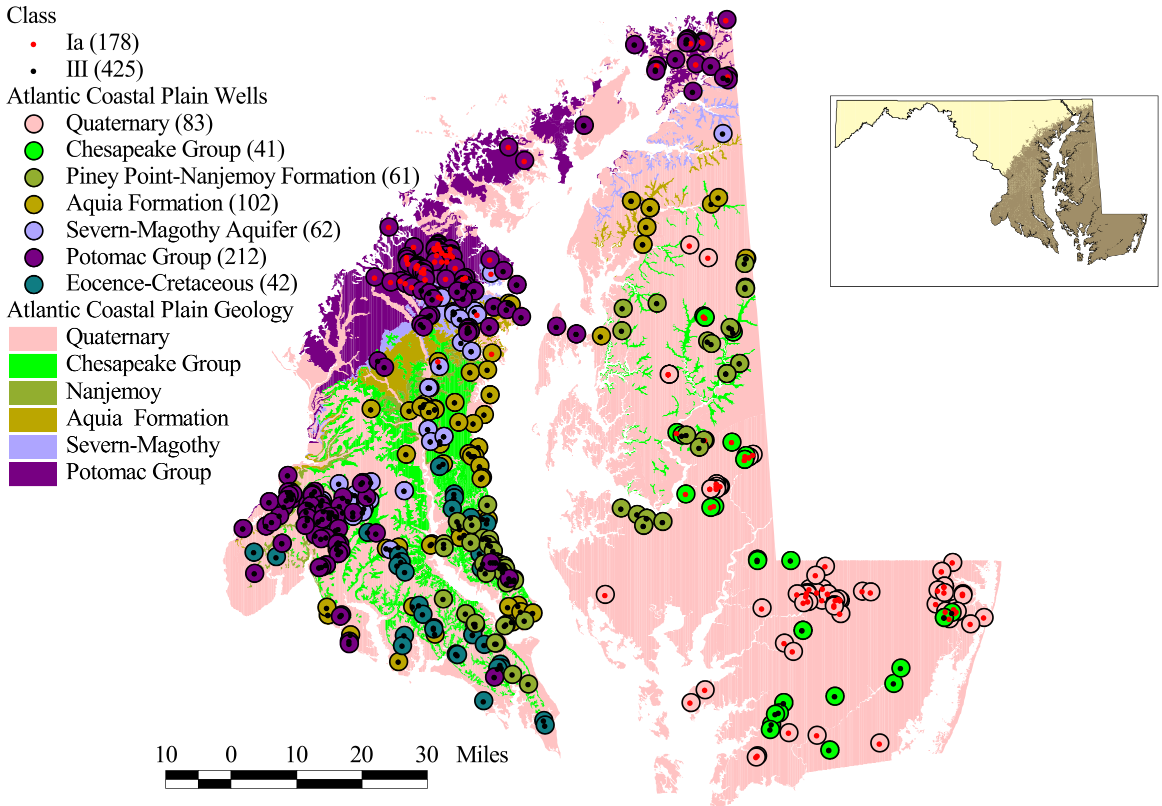

FIGURE 3. Groundwater wells with Pettyjohn classification, and source aquifers that are located in the Atlantic Coastal Plain province. The wells are color coded to match the aquifer outcrop, and the small dot in the middle of the well symbol indicates whether the well is a Class Ia or Class III.

The Coastal Plain is bounded to the west by the Piedmont and Blue Ridge provinces. Both of these provinces contain crystalline igneous and metamorphic rocks that are low-yield aquifers. Triassic basins located within the Piedmont province contain some high-yield consolidated sandstone aquifers. The western part of the state is within the Valley and Ridge and Appalachian Plateaus provinces, both of which contain limestone and sandstone aquifers.

As shown in Table 1, there are 14 primary aquifers in Maryland (summarized from the 1997 U.S. Geological Survey publication "Groundwater Atlas of the United States, Segment 11" and Pettyjohn et al., 1991). The aquifer classification given in Table 1 describes the characteristics of each aquifer and, in particular, the characteristics in the outcrop areas.

TABLE 1. Maryland's aquifers and their classification according to the Pettyjohn classification scheme, only for the outcrop belt of the aquifer.

Name	Description	Pettyjohn Classification
Surficial aquifer system	Unconsolidated, Quaternary permeable gravel, sand and gravel, and sand deposited in a variety of surficial environments	Class Ia because it is surficial, unconsolidated, and consists of permeable deposits of coarse sediments
Chesapeake	Unconsolidated to semi-consolidated, Oligocene-Pliocene permeable coarse-grained sediments (gravel to sand)	Class Ia because it is permeable and not highly consolidated
Piney Point-Nanejemoy	Unconsolidated to semi-consolidated, Eocene-Oligocene permeable coarse-grained sediments (glauconitic sand)	Class Ia because it is permeable and not highly consolidated. However, all of the wells that derive water from this aquifer are Class III because of confining units
Aquia-Rancocas	Unconsolidated to semi-consolidated, Paleocene permeable coarse-grained sediments (glauconitic sand)	Class Ia because it is permeable and not highly consolidated. However, all of the wells that derive water from this aquifer are Class III because of confining units
Severn-Magothy	Unconsolidated to semi-consolidated, late Cretaceous permeable sand and sandstone	Class Ia because it is permeable and not highly consolidated. However, all of the wells that derive water from this aquifer are Class III because of confining units
Potomac	Unconsolidated to semi-consolidated, Cretaceous permeable sand and sandstone	Class Ia because it is permeable and not highly consolidated
Triassic	Consolidated sandstones with high permeability and yield	Class IIa because of the high relative permeability and high yields (typically >50 gpm), except for one well
Paleozoic	Highly consolidated Paleozoic sedimentary or crystalline rocks	Class IIb because of the low yield
Pennsylvanian	Consolidated rocks of different composition (sandstones, lime-stones and shales) with low yields	Class IIb because of the low relative permeability and low yield (typically <50 gpm)
Mississippian limestones	Carbonate rocks with solution features and/or fractures	Class Ib because of high permeability

TABLE 1. Continued.

Name	Description	Pettyjohn Classification
Silurian and Devonian	Carbonate rocks with solution features and/or fractures	Class Ib because of high permeability
Devonian to Ordovician sandstones	Consolidated sandstones	Class IIa because of high yield
Ordovician to Cambrian carbonates	Carbonate rocks with solution features and/or fractures	Class Ib because of high permeability
Pre-Cambrian rocks	Highly consolidated sedimentary or crystalline rocks with low permeabilities and low yields in Blue Ridge and Piedmont provinces	Class IIb because of the low relative permeability and low yield (typically <50 gpm)

Data Sources

The data for drinking water resources in Maryland are maintained by the Maryland Department of the Environment (MDE), Public Drinking Water Program. MDE provided Arc/INFO coverages for all of the water supplies, including groundwater wells, surface water intakes, springs, and names of communities with wellhead protection programs. The digital data contained well depth and numeric codes for identifying the source aquifers. Additional hardcopy printouts which identified the geologic codes were obtained from MDE. MDE provided separate files for CWS and NTNCWS wells, eliminating the need to apply filter criteria 1. Surficial geology data were obtained from the MDE Technical and Regulatory Services Administration. Filter criteria 3 could not be applied in Maryland because data were not available to determine if the water systems had an adequate alternative source of water.

Data Quality

Determining the Pettyjohn classification is the primary objective; however, a system was implemented for tracking the spatial and attribute accuracy of the data in order to maintain a record of the decisions made and to allow checking of the resulting USAs. A "quality" variable was added to the data (Table 2).

TABLE 2. Quality ranks and descriptions.

Quality Rank	Description of the Data Quality
1	source information is available, the well is located within the boundary of the associated data layer (e.g., alluvial valley; geologic formation), and well depths agree with known aquifer depths
2	source information is available, well depths agree with known aquifer depths, and the well is located within the spatial tolerance of the associated data layer
3	source information is available, well depths agree with known aquifer depths, and the well is located beyond the spatial tolerance of the associated data layer
4	source information is not available, but depth of well and its location relative to other wells in the area are in agreement with known aquifer attributes
5	neither source nor depth of the well are available, but, distance to nearest aquifer and geographic position relative to other wells are in agreement with known aquifer attributes

Processing Steps

Every public water supply (PWS) well in Maryland was classified according to the Pettyjohn scheme. The well data contain attributes for water source(s) and well depth. A well can have multiple sources, but the shallowest source (casing depth) was used in the processing steps because it is the one most likely to be impacted by pollutants moving downward from the surface. The surficial geology data were instrumental in classifying the sensitivity of the wells and were analyzed to determine boundaries for aquifer outcrops.

The steps below outline the Geographic Information System (GIS) processing that was performed in deriving the final classification of the wells and generation of the USAs.

1. The groundwater data, consisting of a data layer of 582 CWS and a data layer of 558 NTNCWS wells, were joined together to produce a single data layer.

2. The source aquifer was identified with an aquifer code. The items aquname and usgsname were added to the layer Wellpt. The field aquname was updated based on the aquifer codes and aquifer names by MDE (Norman Lazerus (410) 631-3714). The field usgsname was updated provided on a list of codes from USGS groundwater. USGS list gives era, period, and epoch information, whereas the Maryland list is more detailed, giving the formation name (Helderburg Group).

3. The data layer mdgeol was updated by adding the field geocode. This code was based on geologic formations, which have the same names in both the aquifers as well as the geology. Therefore, the code is the same as used in the Wellpt coverage for identifying source aquifers. Using this code facilitated the selection process. Geocode was update from the list sent by Maryland.

4. The Wellpt was intersected with the mdgeol data layer to identify the surficial geologic feature in which each of the wells were located, creating the data layer usa_well.

5. Items for Pettyjohn classification (CLASS) and data quality (QUALITY) were added to the usa_well.

6. Wells that had a source aquifer identified were assigned a Pettyjohn classification, according to the rules provided by the project geologist, and a Quality Rank of 1.

7. For the wells that were outside of the aquifer outcrop, the spatial tolerance was checked to determine if the well was located within 900 feet of the outcrop based on the metadata description of accuracy for groundwater well locations (+/- 500 feet) and surficial geology boundaries (+/- 400 feet). If so, then a Quality Rank of 2 was assigned.

8. All the wells with no source aquifer, but with depth attributes, were classified based on depth, outcrop in which the well was located, and proximity to classified wells. These wells were assigned the same classification as the nearby classified well based on the following:

   a. The wells were within 3,000 m of each other.

   b. The wells were located in the same surficial geology formation.

   c. The wells had similar depths (± 10 percent); or the unclassified well was deeper than the classified well which was a Class III; or the unclassified well was shallower than the classified well which was a Class Ia. These wells were assigned a Data Quality of 4.

9. Wells with no source aquifer or depth information were classified, when

possible, based on the surrounding wells and geologic formations. These wells were assigned a Quality Rank 5.

10. All of the wells that were not classified were marked as 'UNK' for unknown.

11. All Class Ia, Ib, and IIa wells were extracted and a USA layer was generated that buffered these wells the default distance of 2,000 feet.

12. A USA point data layer was generated by combining the springs data layer and the surface water intakes.

The results are presented below by aquifer, in order from youngest to oldest (Fig. 4), as listed in Table 1.

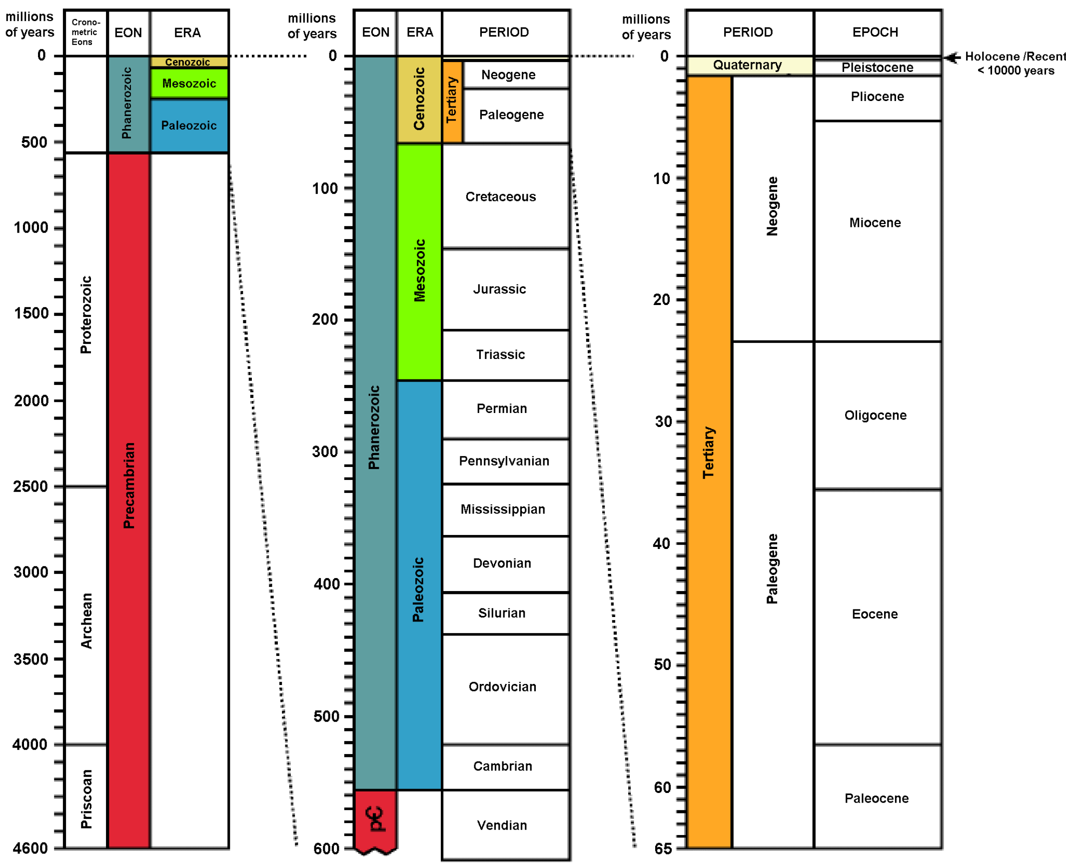

FIGURE 4. Geologic time scale.

RESULTS BY AQUIFER SYSTEM

I. Surficial Aquifer System (Quaternary)

A total of 83 wells obtained water from the surficial aquifer system. The surficial aquifer, which is located within the Atlantic Coastal Plain province, consists of unconsolidated sand and gravel of marine and nonmarine origin. All of these wells were Class Ia because this aquifer is located at the land surface and is composed of highly permeable sediments. All of these wells were located on the Delmarva Peninsula (Fig. 5). There were 34 wells that had a Quality of 1, 30 wells had a Quality of 4, and 19 wells had a Quality of 5 (Table 3). The 30 wells with a Quality of 4 did not have source information, but the shallow depths of the wells indicated that the water was derived from the surficial aquifer.

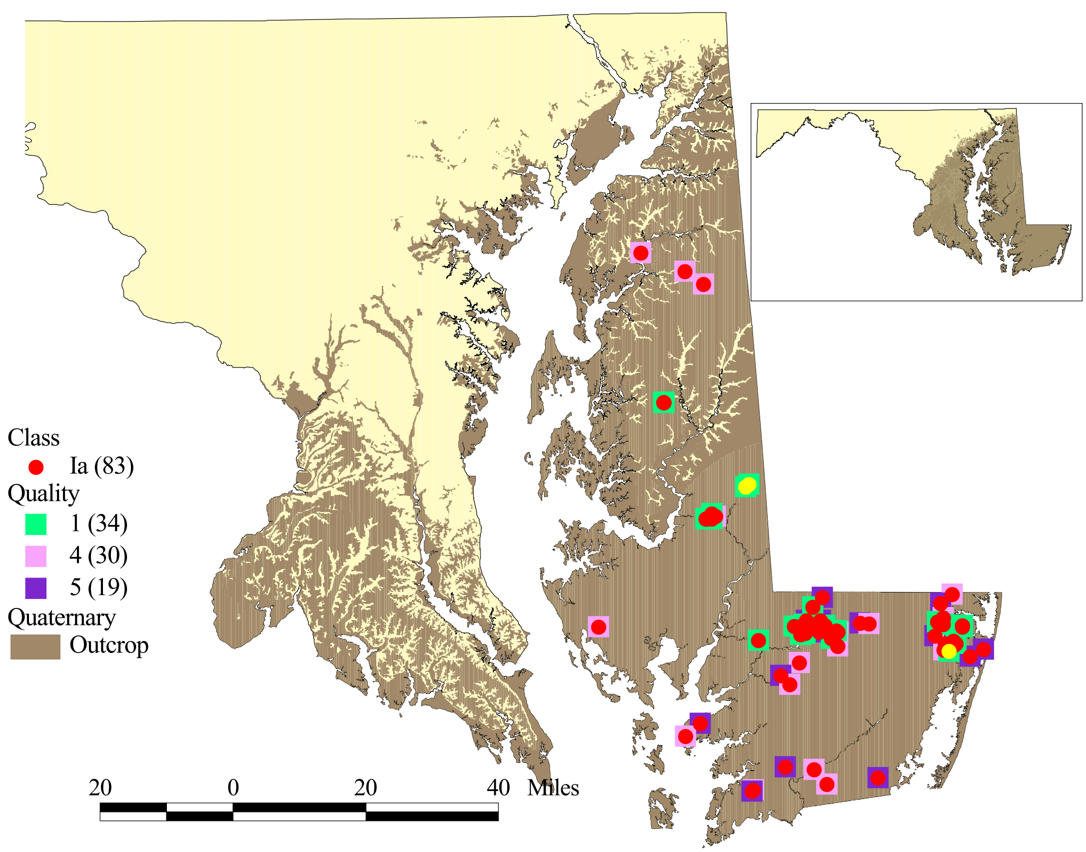

FIGURE 5. Groundwater wells, by Pettyjohn classification and data quality, that obtained water from the surficial aquifer system. All 83 of these wells were Class Ia.

Nineteen wells had no source or depth information, but distance to nearest aquifer and geographic position relative to other wells was in agreement with known aquifer attributes (e.g., its stratigraphic position). These wells were given a Quality of 5.

TABLE 3. Number of wells, Pettyjohn class, and quality rank for surficial aquifers.

Number	Class	Quality
34	Ia	1
30	Ia	4
19	Ia	5

II. Chesapeake Aquifer (Oligocene-Pliocene)

Forty-one wells derived water from this aquifer, which consists of six local sand aquifers separated by minor confining units (USGS, 1997). All of the wells were located within the Atlantic Coastal Plain province (Fig. 6). Wells that occurred within the outcrop belt of the aquifer or near the Delaware border on the Delmarva Peninsula were Class Ia (13). The 28 wells that were located elsewhere were Class III, because it was assumed that the aquifer was confined by overlying impermeable units. There were 25 wells assigned a Quality of 1 and 16 wells assigned a Quality of 4 (Table 4).

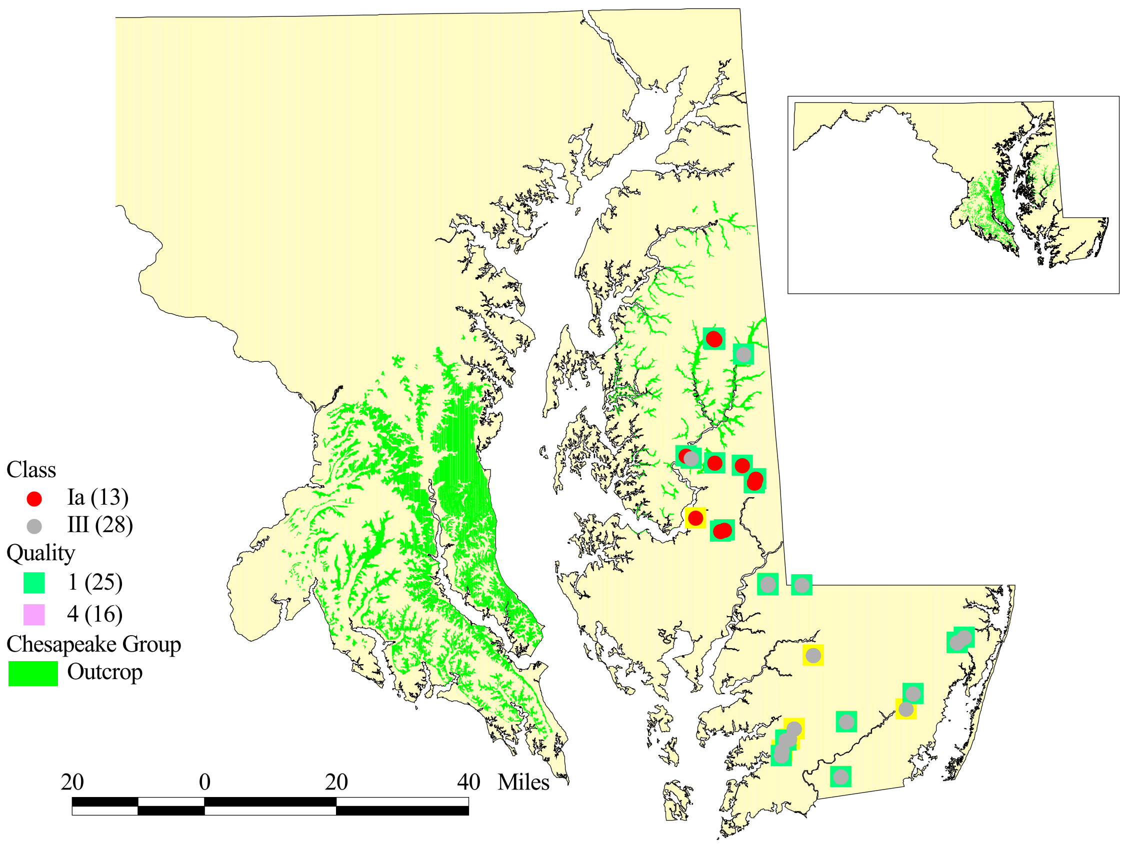

FIGURE 6. Groundwater wells, by Pettyjohn classification and data quality, that obtained water from the Chesapeake aquifer. Thirteen of these wells were Class Ia and 28 were Class III.

TABLE 4. Number of wells, Pettyjohn class, and quality rank for the Chesapeake aquifer.

Number	Class	Quality
12	Ia	1
1	Ia	4
13	III	1
15	III	4

III. Piney Point-Nanejemoy Aquifer (Eocene-Oligocene)

A total of 61 wells derived water from this aquifer, which consists of unconsolidated, medium to coarse glauconitic sand (USGS, 1997). All of these wells were Class III, because the producing zone is far down dip from the outcrop belt and overlain by confining units. The wells occurred in a northeast/southwest-oriented band in the central portion of the Atlantic Coastal Plain province (Fig. 7). There were 49 wells that had Quality of 1 and 12 wells that had Quality of 4 (Table 5).

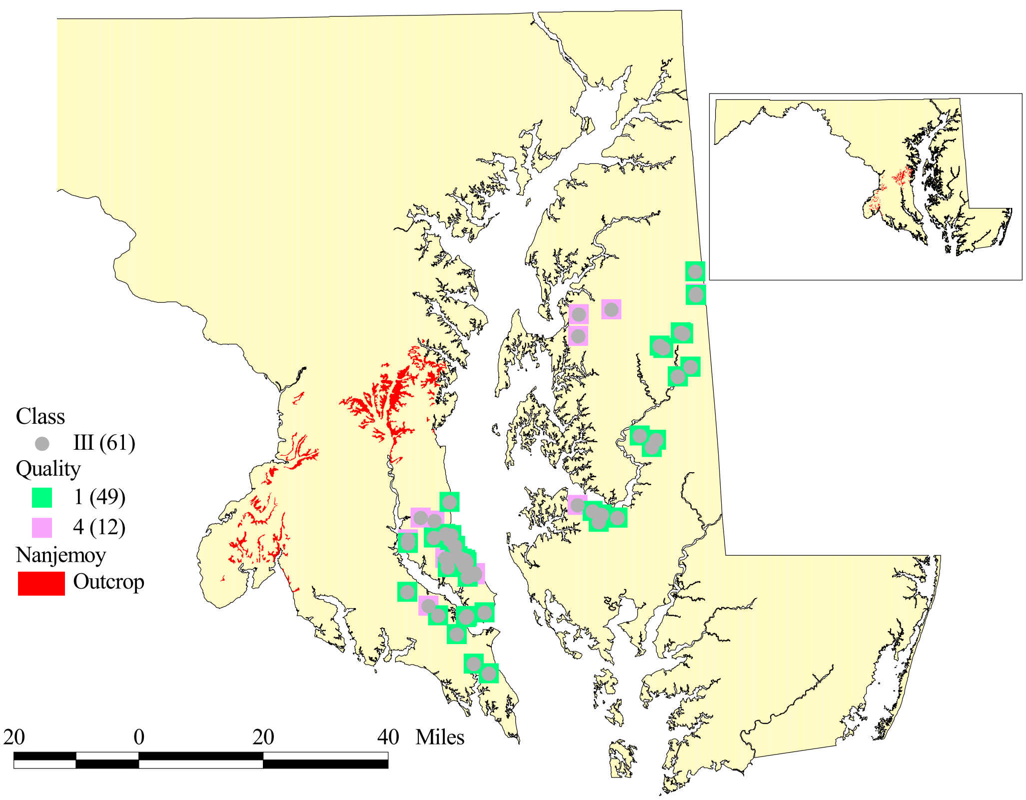

FIGURE 7. Groundwater wells, by Pettyjohn classification and data quality, that obtained water from the Piney Point-Nanejemoy aquifer. All 61 of these wells were Class III.

TABLE 5. Number of wells, Pettyjohn class, and quality rank for the Piney Point-Nanejemoy aquifer.

Number	Class	Quality
49	III	1
12	III	4

IV. Miscellaneous Eocene to Cretaceous Wells

There were 42 wells that occurred throughout the Atlantic Coastal Plain province that were assigned a Quality of 5 (Fig. 8). Although no well source or depth information were provided for these wells, their location in the middle coastal plain and data from nearby wells implied a designation of Class III, because of the confining units within the upper sedimentary units of the middle coastal plain. It was assumed that these were all relatively deep wells, because other wells in this area were Class III (i.e., their aquifers are confined).

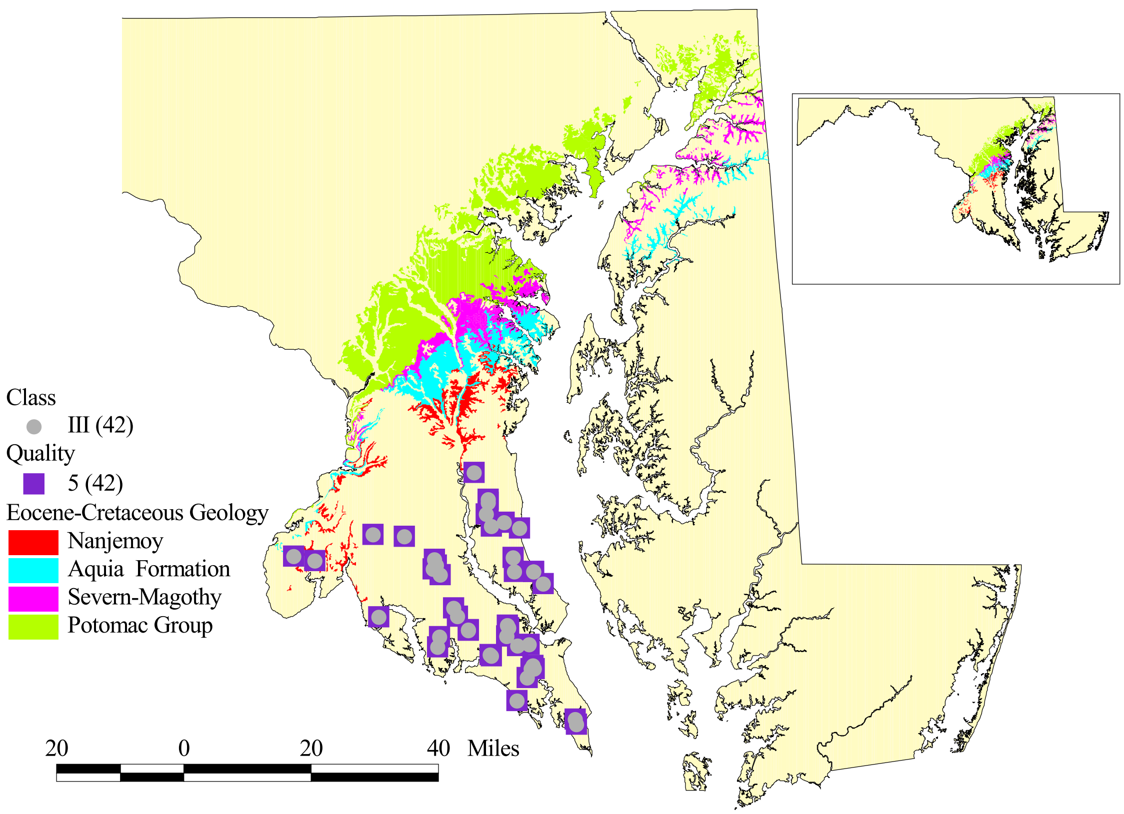

FIGURE 8. Groundwater wells, by Pettyjohn classification and data quality, that obtained water from wells from Eocene to Cretaceous age that had a Quality Rank of 5 (well classified using their geologic position and class of nearby wells). All 42 of these wells were Class III.

V. Aquia Aquifer (Paleocene)

This aquifer underlies the Piney Point-Nanejemoy aquifer and is made up of similar sandy sediments. A confining unit composed of silt and clay separates the two aquifers (USGS, 1997). A total of 102 wells derived water from this aquifer. The two wells located within the outcrop belt were Class Ia. The 100 wells outside the outcrop belt were Class III. There were 85 wells with Quality of 1 and 17 wells with Quality of 4 (Table 6).

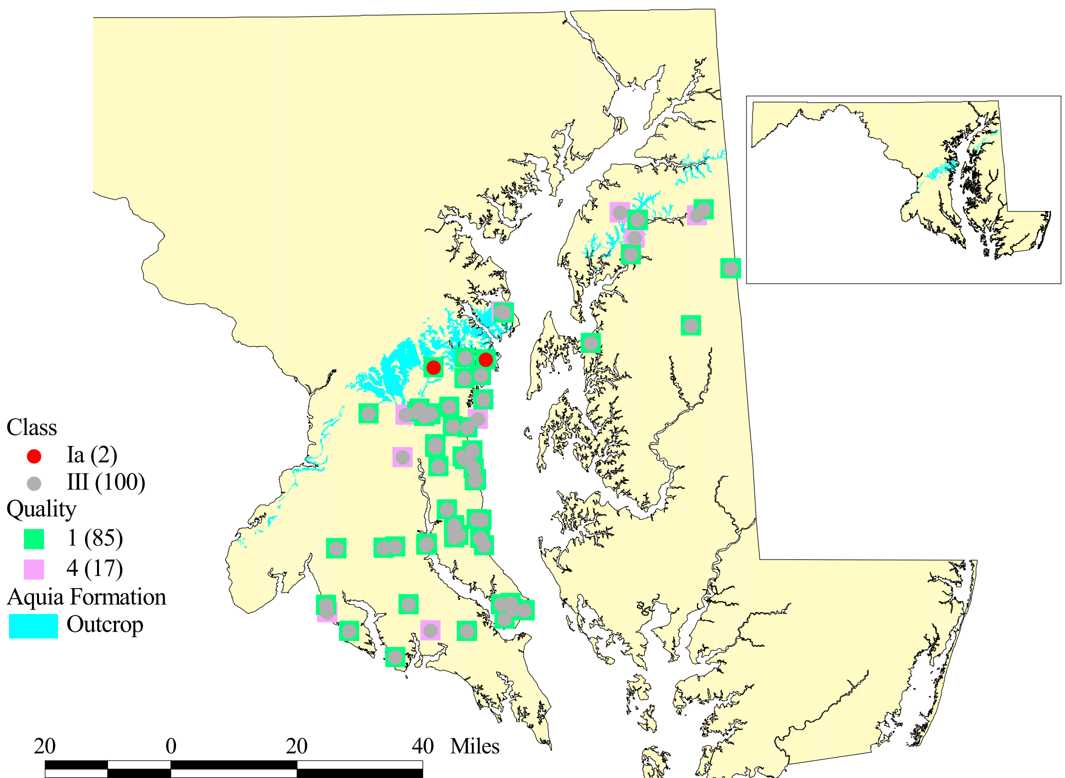

FIGURE 9. Groundwater wells, by Pettyjohn classification and data quality, that obtained water from the Aquia aquifer. Only the two wells in the outcrop belt are Class Ia; the other 100 wells are Class III.

TABLE 6. Number of wells, Pettyjohn class, and quality rank for the Aquia aquifer.

Number	Class	Quality
2	Ia	1
83	III	1
17	III	4

VI. Severn-Magothy Aquifer (Late Cretaceous)

This aquifer, which crops out along the western margin of the Atlantic Coast Coastal Plain province, consists of permeable, unconsolidated sand deposits of late Cretaceous age. The ten wells located within the outcrop belt were Class Ia (Fig. 10). The remaining 52 wells were Class III, because the producing horizons for these wells occurred under younger confining units. There were 60 wells with Quality of 1 and two wells with Quality of 4 (Table 7).

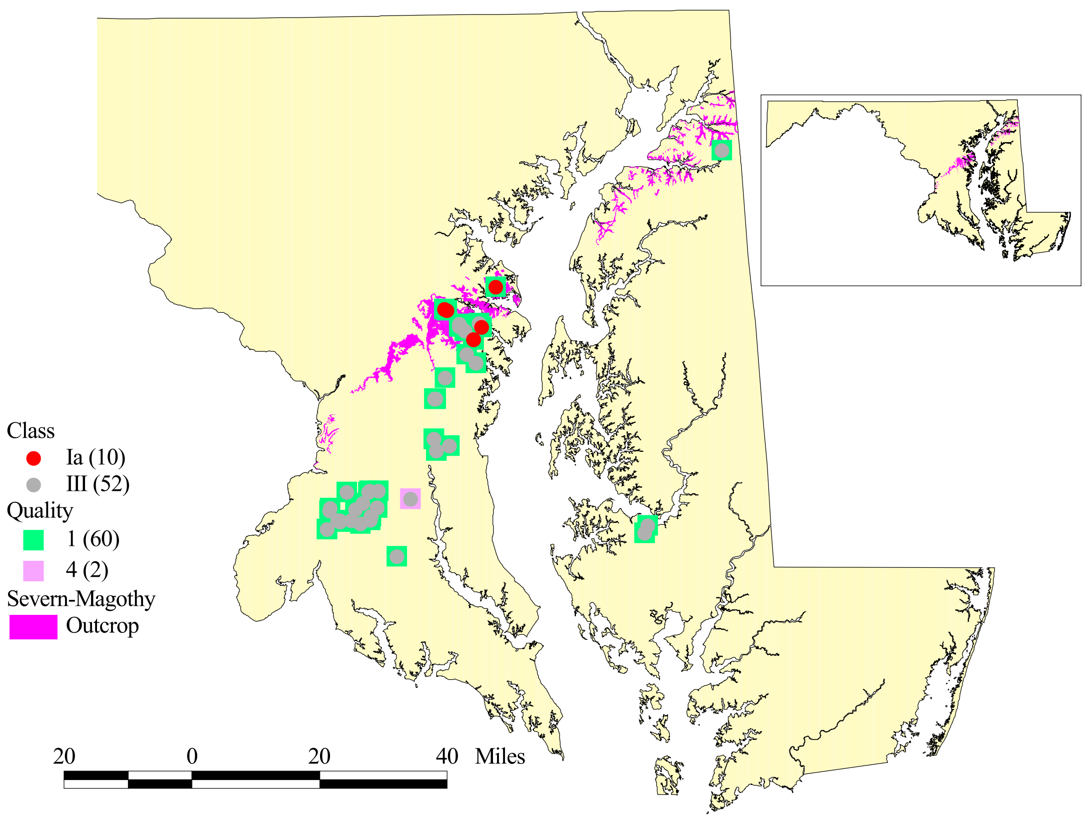

FIGURE 10. Groundwater wells, by Pettyjohn classification and data quality, that obtained water from the Severn-Magothy aquifer. Ten of these wells were Class Ia and the remaining 52 were Class III.

TABLE 7. Number of wells, Pettyjohn class, and quality rank for the Severn-Magothy aquifer.

Number	Class	Quality
10	Ia	1
50	III	1
2	III	4

VII. Potomac Aquifer (Cretaceous)

A total of 212 wells derived water from this Lower Cretaceous aquifer, which consists of permeable sand and gravel of riverine and deltaic origin (USGS, 1997). In the outcrop belt, there were 70 Class Ia wells. The remaining 142 wells were Class III, because the aquifer was overlain by younger confining units (Fig. 11). There were 179 with Quality 1, two wells with Quality 3, 28 wells with Quality 4, and three wells with Quality 5 (Table 8).

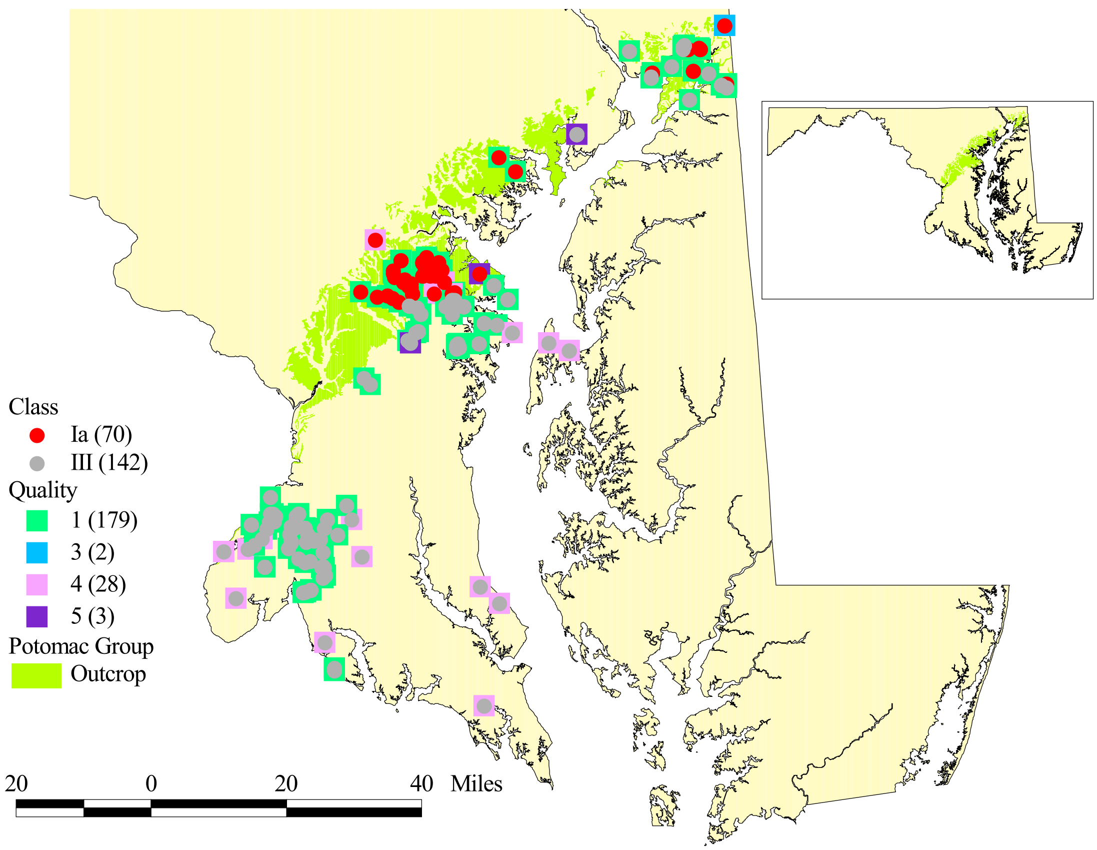

FIGURE 11. Groundwater wells, by Pettyjohn classification and data quality, that obtained water from the Potomac aquifer. Seventy of these wells were Class Ia and the remaining 142 were Class III.

TABLE 8. Number of wells, Pettyjohn class, and quality rank for the Potomac aquifer.

Number	Class	Quality
63	Ia	1
2	Ia	3
4	Ia	4
1	Ia	5
116	III	1
24	III	4
2	III	5

VIII. Triassic Sandstone Aquifers

High-yield, consolidated sandstones and conglomerates of Triassic age occurred in fault basins located within the Piedmont province in central Maryland. Of the 25 wells that derived water from these sandstones, 24 of the wells were Class IIa and one was Class IIb, because it had a yield of <50 gpm (Fig. 12). There were 11 wells with Quality 1, seven wells with Quality 4, and seven wells with Quality 5 (Table 9).

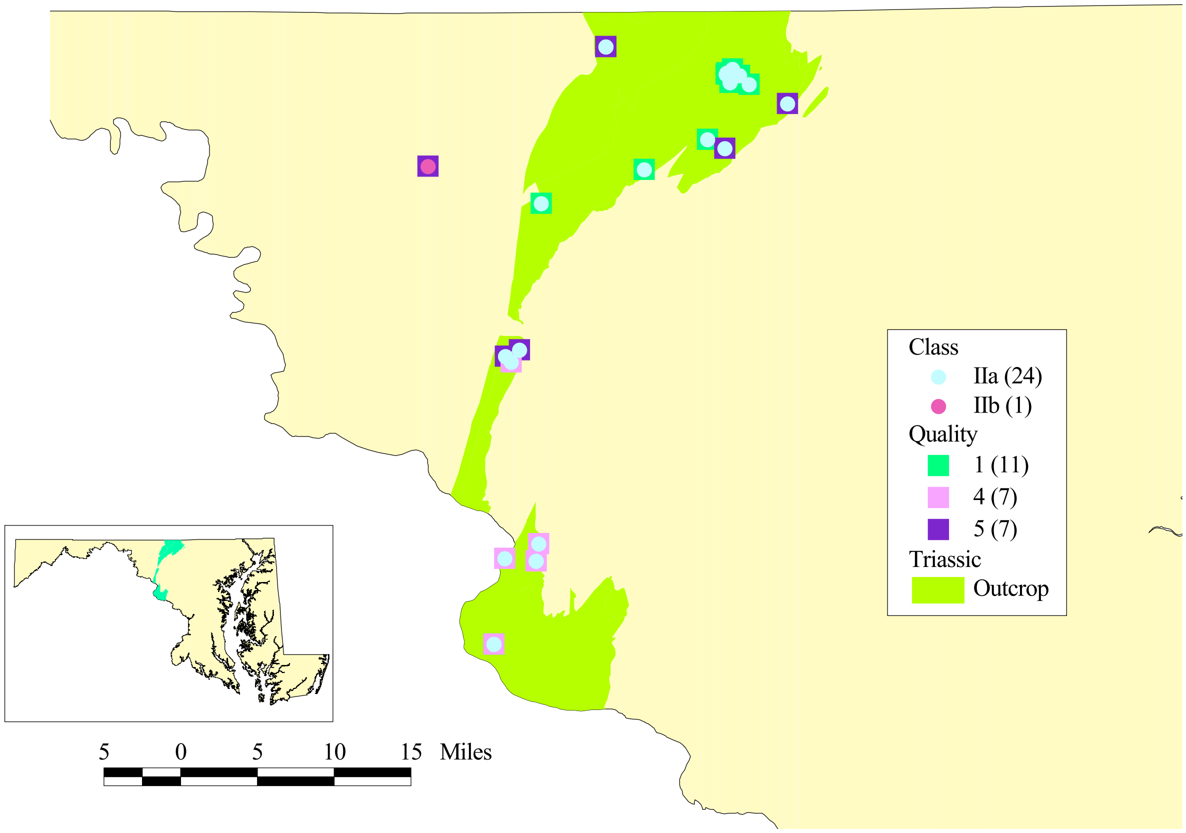

FIGURE 12. Groundwater wells, by Pettyjohn classification and data quality, that obtained water from Triassic sandstones. All but one of these wells were Class IIa.

TABLE 9. Number of wells, Pettyjohn class, and quality rank for Triassic sandstone aquifers.

Number	Class	Quality
11	IIa	1
7	IIa	4
6	IIa	5
1	IIb	5

IX. Paleozoic Highly Consolidated Sedimentary or Crystalline Rocks

A total of 394 wells derived water from the highly consolidated sedimentary or crystalline rocks of Paleozoic age that are located within the Piedmont and Blue Ridge provinces of east-central Maryland (Fig. 13). Because of the typically low yields of these wells, 354 of them were Class IIb. The remaining 40 were Class III, because they were overlain by a confining unit. There were 236 wells with Quality of 1, 91 wells with Quality of 4, and 67 wells with Quality of 5 (Table 10).

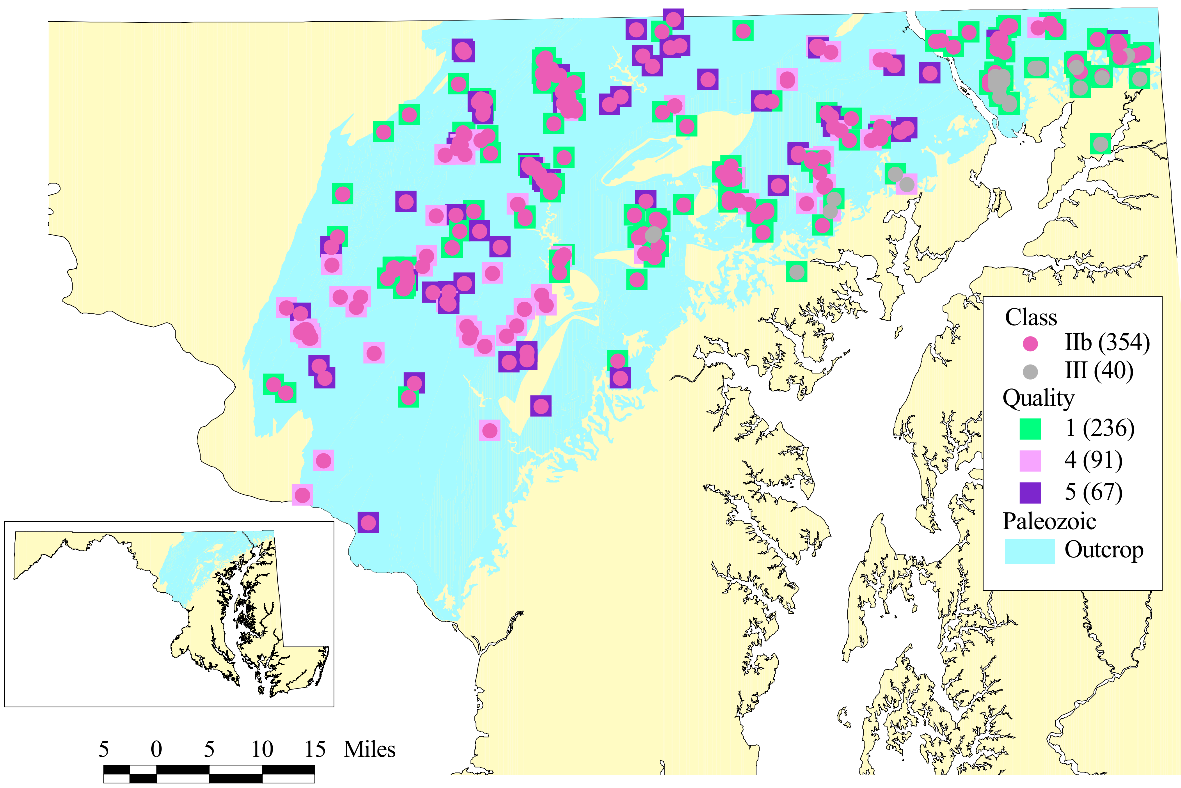

FIGURE 13. Groundwater wells, by Pettyjohn classification and data quality, that obtained water from Paleozoic highly consolidated sedimentary and crystalline rocks of the Blue Ridge and Piedmont provinces. Of these wells, 354 were Class IIb and the remaining 40 were Class III.

TABLE 10. Number of wells, Pettyjohn class, and quality rank for Paleozoic highly consolidated sedimentary or crystalline rock aquifers.

Number	Class	Quality
36	III	1
4	III	4
200	IIb	1
87	IIb	4
67	IIb	5

X. Low Yield Pennsylvanian Sedimentary Rocks

A total of 35 wells derived water from the Pennsylvanian sedimentary rocks of western Maryland. Because of their highly consolidated nature and low yields, the 35 wells were all Class IIb (Fig. 14). There were 22 wells with Quality of 1, eight wells with Quality of 4, and five wells with Quality of 5 (Table 11).

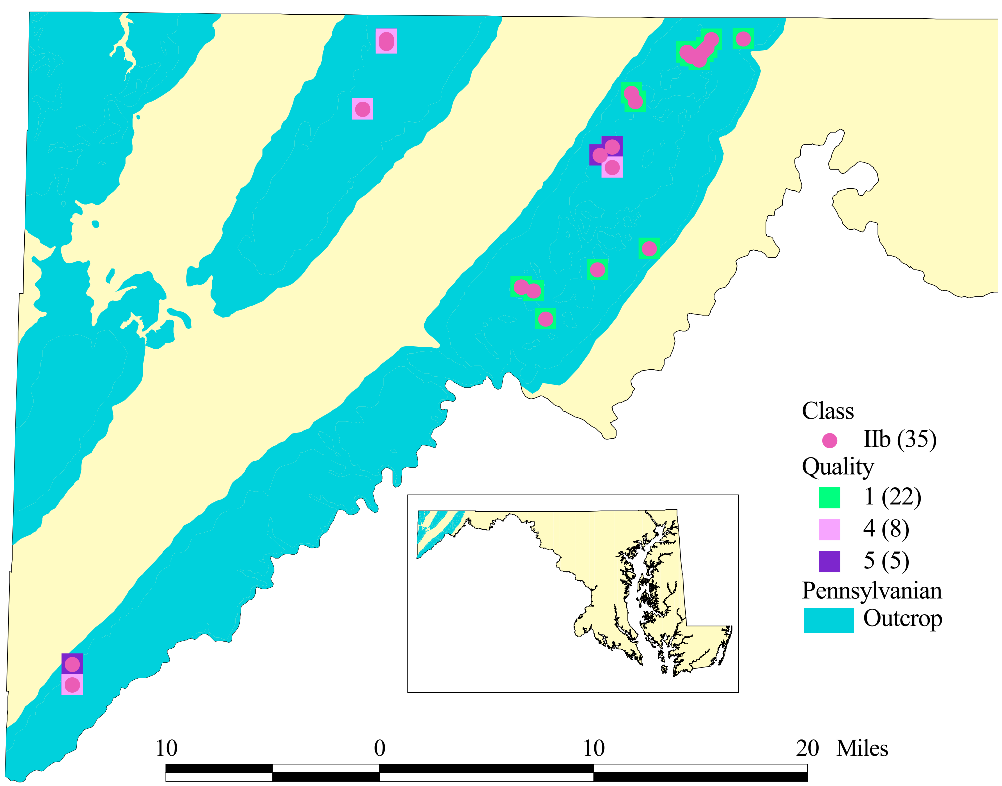

FIGURE 14. Groundwater wells, by Pettyjohn classification and data quality, that obtained water from Pennsylvanian sedimentary rocks. All 35 of these wells were Class IIb.

TABLE 11. Number of wells, Pettyjohn class, and quality rank for Pennsylvanian sedimentary rock aquifers.

Number	Class	Quality
22	IIb	1
8	IIb	4
5	IIb	5

XI. Mississippian Limestones

A total of 11 wells located in the far western part of the state derived water from Mississippian limestones. Because of the presence of solution features within these rocks and their location within the limestone outcrop belt, all of the wells were Class Ib (Fig. 15). There were seven wells with Quality of 1, two wells with Quality of 4, and two wells with Quality of 5 (Table 12).

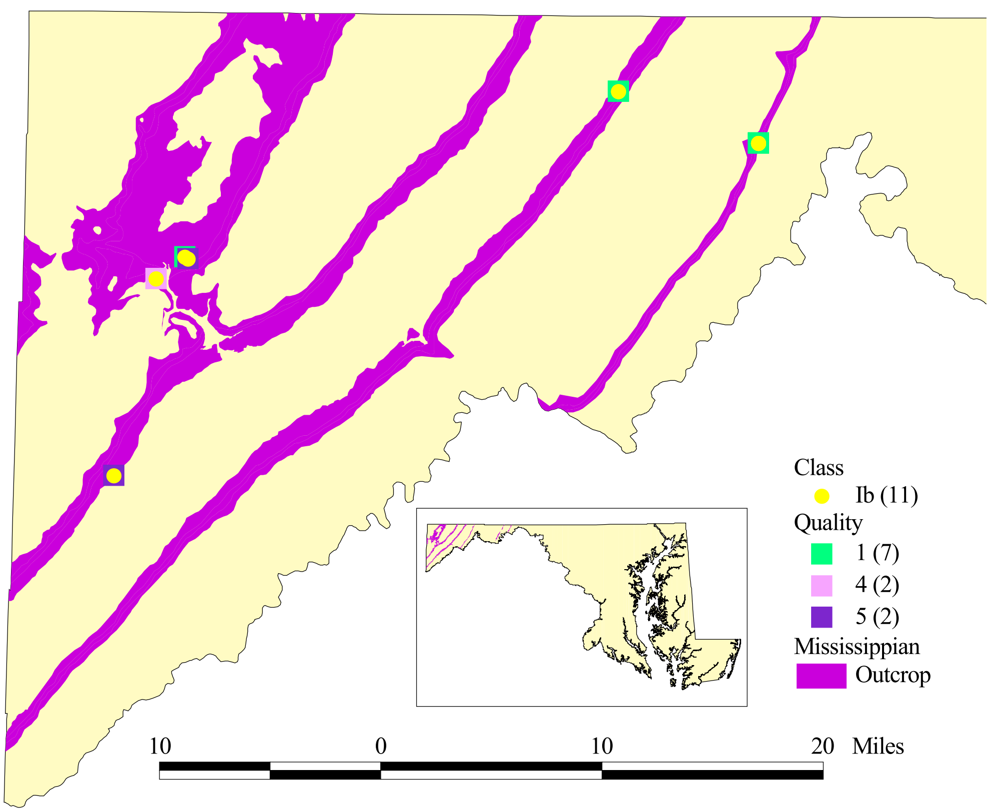

FIGURE 15. Groundwater wells, by Pettyjohn classification and data quality, that obtained water from Mississippian limestones. All 11 of these wells were Class Ib.

TABLE 12. Number of wells, Pettyjohn class, and quality rank for Mississippian limestone aquifers.

Number	Class	Quality
7	Ib	1
2	Ib	4
2	Ib	5

XII. Silurian and Devonian Carbonates

The one well that derived water from this aquifer is located in the Siluro-Devonian outcrop belt in western Maryland (Fig. 16). This well was a Class Ib because these carbonate rocks contained solution features and/or fractures.

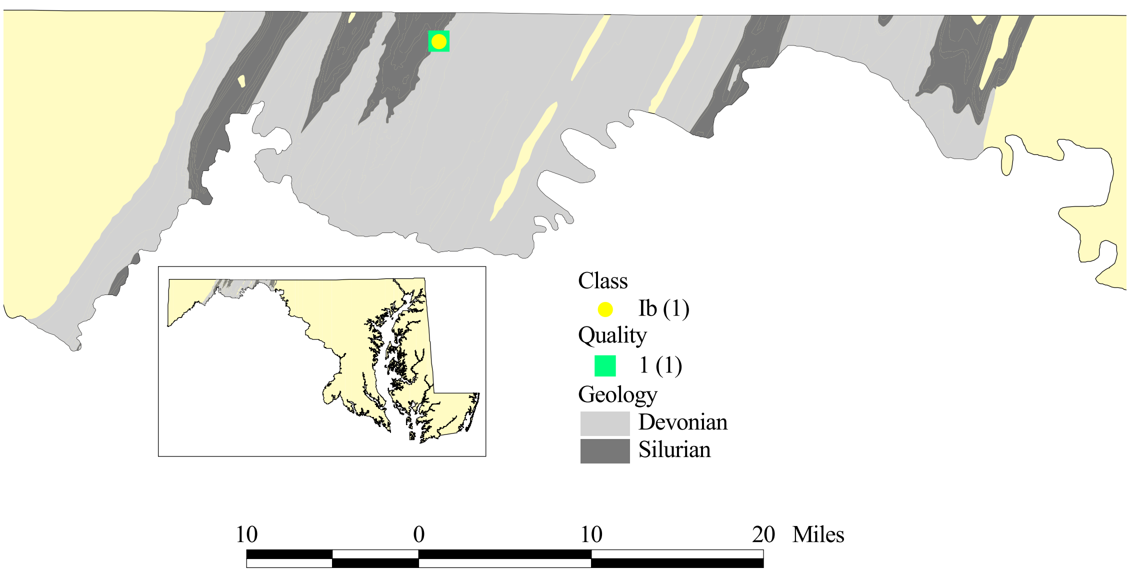

FIGURE 16. Groundwater wells, by Pettyjohn classification and data quality, that obtained water from Silurian to Devonian carbonates. This single well was Class Ib.

XIII. Devonian to Ordovician Sandstones

A total of 13 wells derived water from these sandstones, which are located in western Maryland (Fig. 17). All of the wells were Class IIa because these sedimentary rocks can have production rates greater than 50 gpm. There were seven wells with Quality of 1, three wells with Quality of 4, and three wells with Quality of 5 (Table 13).

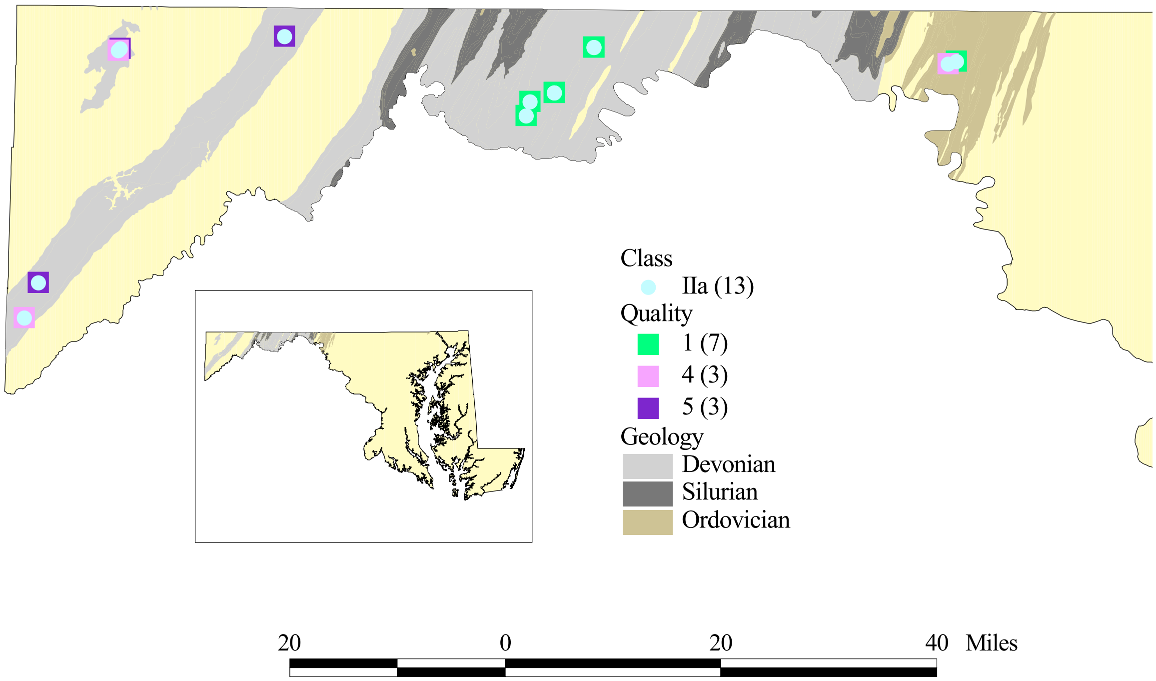

FIGURE 17. Groundwater wells, by Pettyjohn classification and data quality, that obtained water from Devonian to Ordovician sandstones. All 13 of these wells were Class IIa.

TABLE 13. Number of wells, Pettyjohn class, and quality rank for Devonian to Ordovician sandstone aquifers.

Number	Class	Quality
7	IIa	1
3	IIa	4
3	IIa	5

XIV. Ordovician to Cambrian Carbonates

A total of 16 wells derived water from these carbonates, which crop out in central Maryland (Fig. 18). All of the wells were Class Ib because these carbonate rocks contained solution features and/or fractures. There were three wells with Quality of 1, seven wells with Quality of 4, and six wells with Quality of 5 (Table 14).

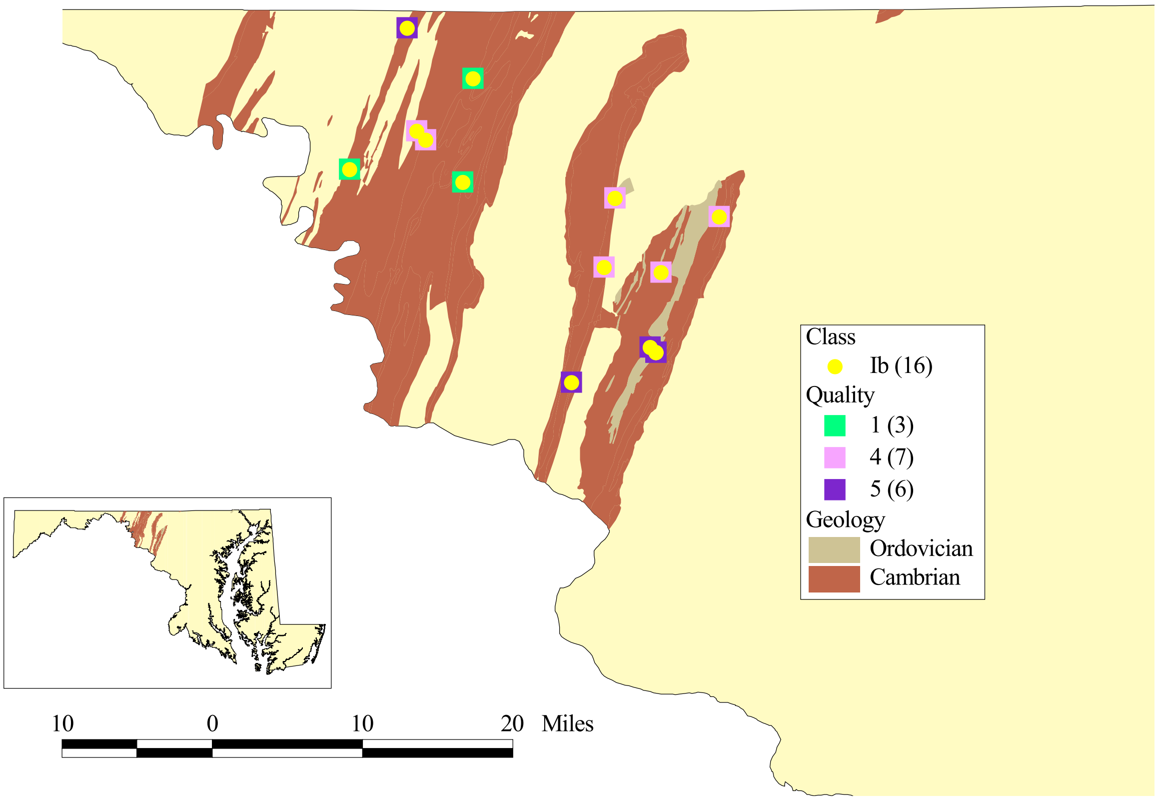

FIGURE 18. Groundwater wells, by Pettyjohn classification and data quality, that obtained water from Cambrian to Ordovician carbonates. All 16 of these wells were Class Ib.

TABLE 14. Number of wells, Pettyjohn class, and quality rank for Ordovician to Cambrian carbonate aquifers.

Number	Class	Quality
3	Ib	1
7	Ib	4
6	Ib	5

XV. Pre-Cambrian Crystalline Rocks

Twenty-two wells derived water from Pre-Cambrian crystalline rocks in the central Maryland area (Fig. 19). All of these wells were Class IIb because they produce from impermeable, low-yield bedrock aquifers. There were 14 wells with Quality of 1, five wells with Quality of 4, and three wells with Quality of 5 (Table 15).

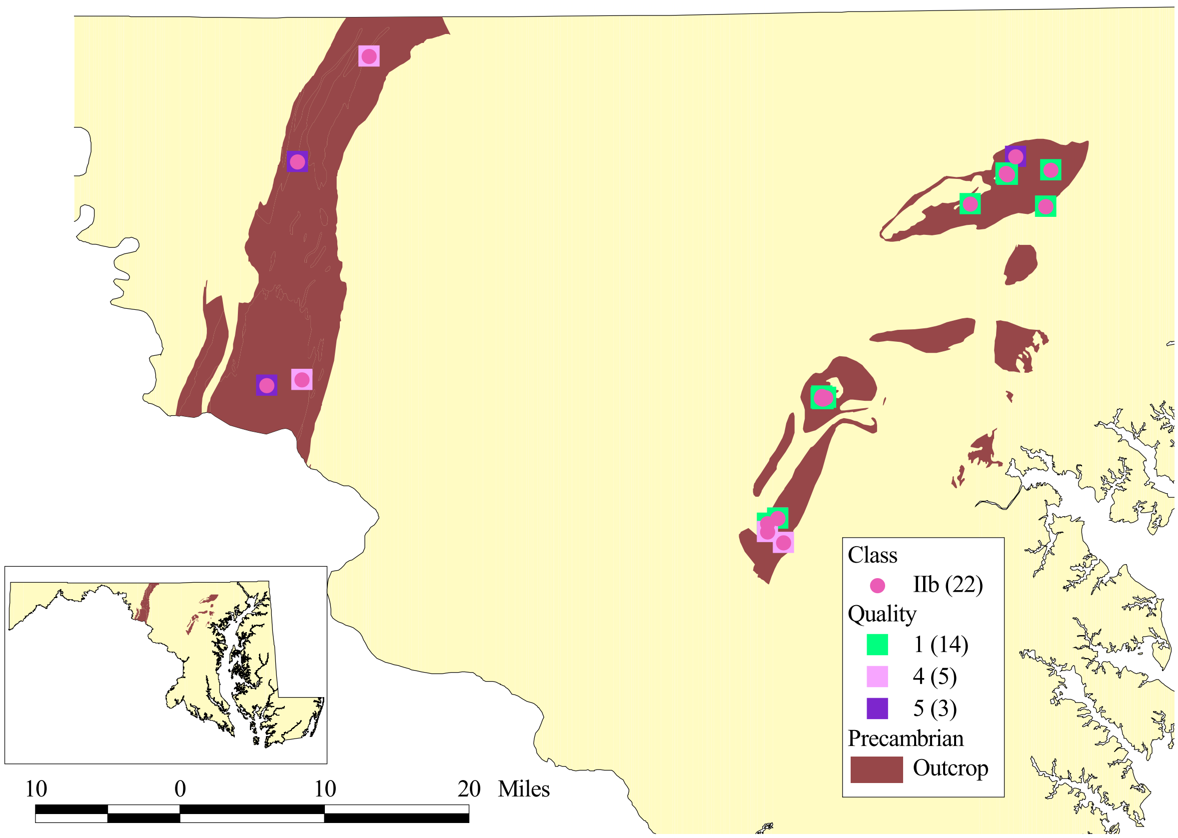

FIGURE 19. Groundwater wells, by Pettyjohn classification and data quality, that obtained water from Pre-Cambrian crystalline rocks. All 22 of these wells were Class IIb.

TABLE 15. Number of wells, Pettyjohn class, and quality rank for Pre-Cambrian crystalline rock aquifers.

Number	Class	Quality
14	IIb	1
5	IIb	4
3	IIb	5

SUMMARY

Of the 1,140 public water supply wells in Maryland, 243 wells (21 percent) were classified as USAs (Fig. 20; Table 16). The final groundwater USAs were derived by selecting all of the Pettyjohn Class Ia, Ib, and IIa wells and creating a 2,000-foot (radius) default buffer zone around the wells. There is no source for Wellhead Protection Areas (WHPA) because these designations are currently being defined by community representatives and are not being reported to a state-level organization. Therefore, to obtain WHPA information, each community needs to be contacted and this is prohibitive at this time.

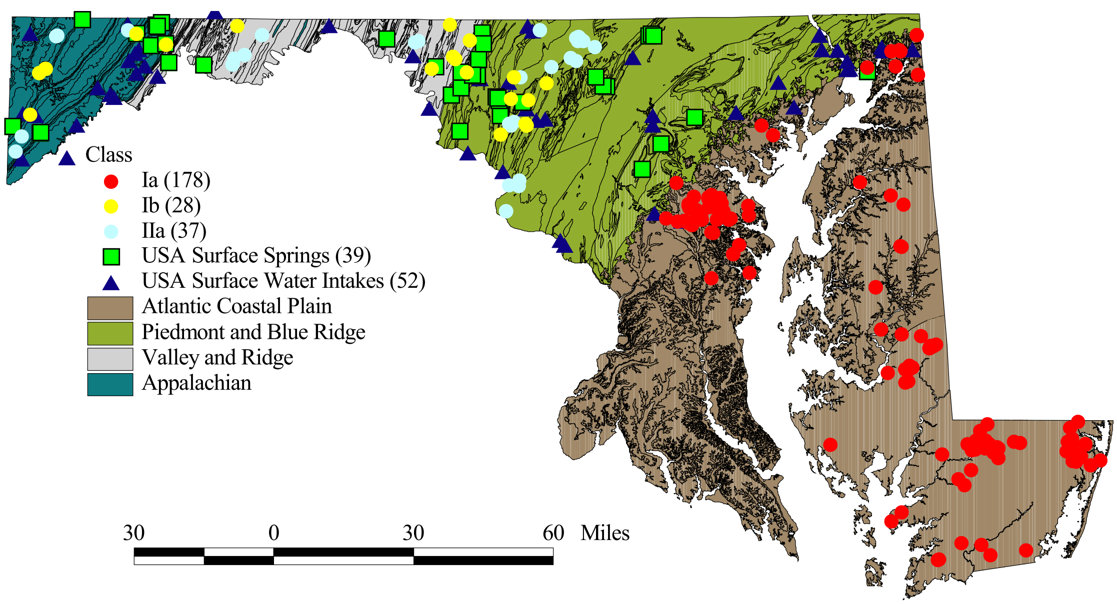

FIGURE 20. Location of surface and groundwater USAs in Maryland.

TABLE 16. Classification of the groundwater USAs in Maryland.

Class	Number of Groundwater Wells	Percentage
Ia	178	15.6
Ib	28	2.5
IIa	37	3.2
IIb	412	36.1
III	465	40.8
Unknown	20	1.8

There were 20 wells with no source or depth information that remained unclassified. Those wells occur in areas where there are multiple layered aquifers and it is not possible to determine the source aquifer (Fig. 21).

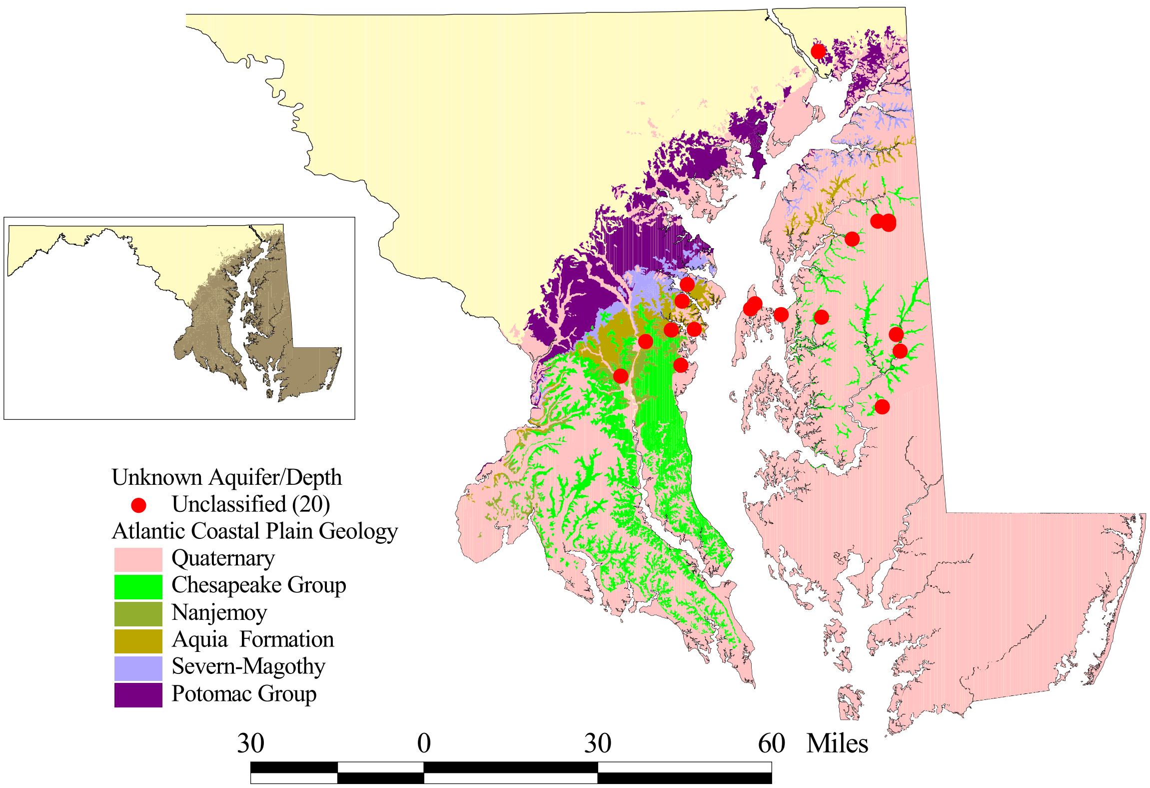

FIGURE 21. Wells not classified because of insufficient data.

The final USAs, as defined using the default WHPA, are depicted in Figure 22. In the GIS database, the USAs have "region" topology, which means that wells that had overlapping USA polygons were still identified by each well and all of the associated attributes of each well (Fig. 23).

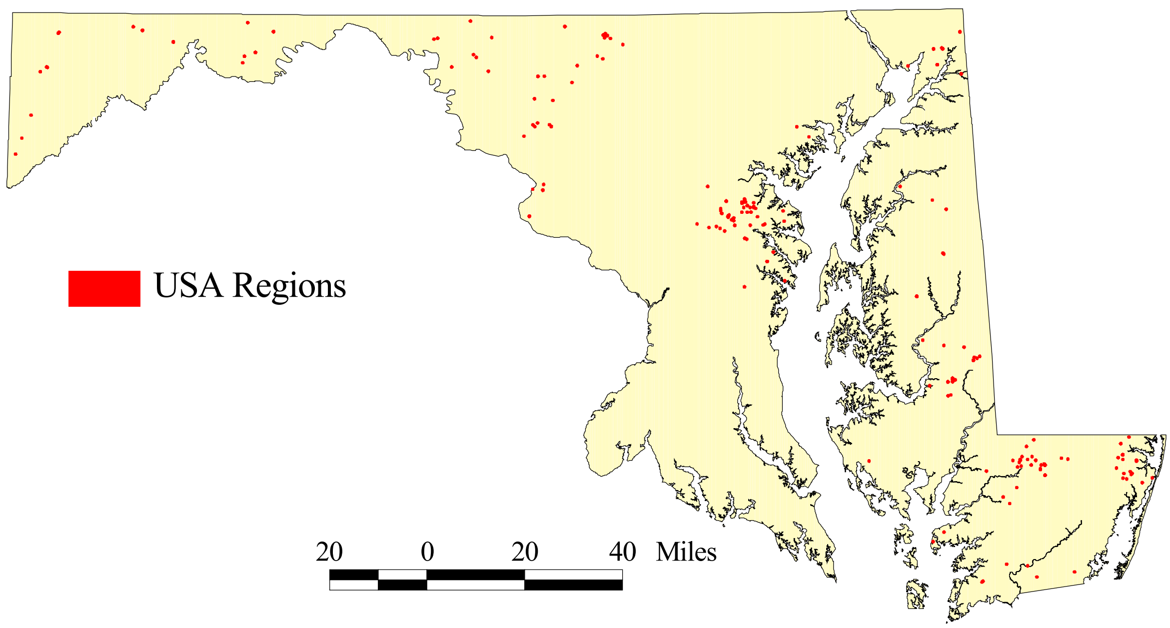

FIGURE 22. Final Maryland drinking water well USAs.

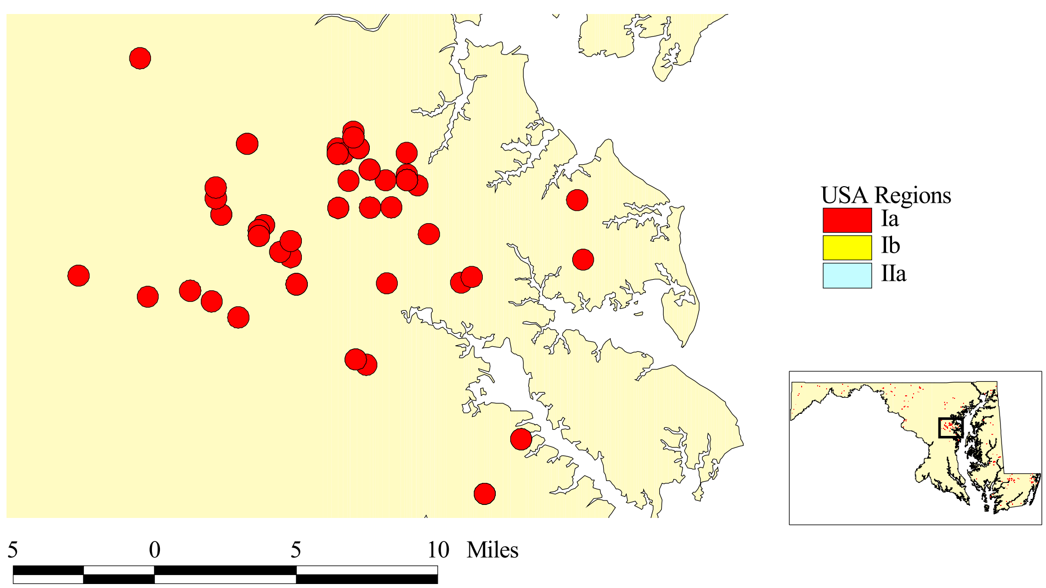

FIGURE 23. Example of Maryland drinking water USAs showing "region" spatial topology.

Data quality is always a concern when performing spatial analysis among various data layers. The most important variable in assessing the Pettyjohn vulnerability classification is the source of the water. A total of 736 (64.6 percent) of the groundwater wells in the database have source information. The Quality Rank of the 243 groundwater USAs in Maryland are shown in Table 17.

TABLE 17. Data quality of the groundwater USAs in Maryland.

Quality Rank	Number of Groundwater USAs	Percentage
1	163	63.4
2	0	N/A
3	2	0.8
4	55	21.4
5	37	14.4

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